

## **Maximum Oxygen Uptake during and after Long-Duration Space Flight**

A.D. Moore, Jr.,<sup>1</sup> S.N. Evetts,<sup>2</sup> A.H. Feiveson,<sup>3</sup> S.M.C. Lee,<sup>4</sup> F.A. McCleary,<sup>5</sup> and S.H. Platts<sup>6</sup>

<sup>1</sup>alan.d.moore@nasa.gov, Wyle Integrated Science and Engineering Group,  
<sup>2</sup>simon.evetts@esa.int, Wyle GmbH, <sup>3</sup>alan.h.feiveson@nasa.gov, NASA Johnson Space Center,  
<sup>4</sup>stuart.lee-1@nasa.gov, Cardiovascular Laboratory, Wyle Integrated Science and Engineering  
Group, <sup>5</sup>frank.a.mccleary@lmco.com, Lockheed Martin, <sup>6</sup>steven.platts-1@nasa.gov, Human  
Adaptation and Countermeasures Division, NASA Johnson Space Center

### **INTRODUCTION**

Decreased maximum oxygen consumption ( $\text{VO}_2\text{max}$ ) during and after space flight may impair a crewmember's ability to perform mission-critical work that is high intensity and/or long duration in nature (Human Research Program Integrated Research Plan Risk 2.1.2: Risk of Reduced Physical Performance Capabilities Due to Reduced Aerobic Capacity). When  $\text{VO}_2\text{max}$  was measured in Space Shuttle experiments, investigators reported that it did not change during short-duration space flight but decreased immediately after flight. Similar conclusions, based on the heart rate (HR) response of Skylab crewmembers, were made previously concerning long-duration space flight. Specifically, no change in the in-flight exercise HR response in 8 of 9 Skylab crewmembers indicated that  $\text{VO}_2\text{max}$  was maintained during flight, but the elevated exercise HR after flight indicated that  $\text{VO}_2\text{max}$  was decreased after landing. More recently, a different pattern of in-flight exercise HR response, and assumed changes in  $\text{VO}_2\text{max}$ , emerged from routine testing of International Space Station (ISS) crewmembers. Most ISS crewmembers experience an elevated in-flight exercise HR response early in their mission, with a gradual return toward preflight levels as the mission progresses. Similar to previous reports, exercise HR is elevated after ISS missions and returns to preflight levels by 30 days after landing.  $\text{VO}_2\text{max}$  has not been measured either during or after long-duration space flight. The purposes of the ISS  $\text{VO}_2\text{max}$  experiment are (1) to measure  $\text{VO}_2\text{max}$  during and after long-duration spaceflight, and (2) to determine if submaximal exercise test results can be used to accurately estimate  $\text{VO}_2\text{max}$ .

### **METHODS**

ISS crewmembers assigned to missions of >90 days duration may volunteer for this study. About 270 days before launch, crewmembers perform a graded exercise test (identical to the MedB4.1 protocol) to volitional fatigue on a cycle ergometer to measure  $\text{VO}_2\text{max}$ . An individualized test protocol based on the results of this test is developed for all subsequent exercise tests. The test protocol begins with three 5-minute exercise stages designed to elicit 25%, 50%, and 75% of preflight  $\text{VO}_2\text{max}$  and continues with 25-watt/min increases until volitional fatigue. Metabolic gas analysis is performed using the Portable Pulmonary Function System (PPFS, DAMEC Research ApS, Odense, DK). Cardiac output is measured by the PPFS using a rebreathing technique ( $\text{R-22/SF}_6$ ) during the final minute of each of the first three exercise stages. These tests are scheduled to be performed 60 and 30 days before launch, monthly during flight, and on recovery days 1, 10, and 30.

### **RESULTS AND DISCUSSION**

At the time of abstract submission, 4 crewmembers were participating in the study but had not completed their respective missions. Unfortunately the PPFS could not be delivered to the ISS in time to support early flight test sessions on 3 of 4 crewmembers, but all crewmembers will complete at least 2 test sessions during flight. These sessions were successfully conducted with only minor issues. By the time of the conference presentation it is anticipated that at least partial sets from 3 of the crewmembers will be available for presentation and discussion.

# Maximum Oxygen Uptake During and After Long Duration Space Flight

Alan D. Moore, Jr., Ph.D.<sup>1</sup>

Simon N. Evetts, Ph.D.<sup>2</sup>

Alan H. Feiveson, Ph.D.<sup>3</sup>

Stuart M.C. Lee, M.S.<sup>1</sup>

Frank A. McCleary, M.S.<sup>4</sup>

Steven H. Platts, Ph.D.<sup>3</sup>

<sup>1</sup> - Wyle Integrated Science and Engineering Group

<sup>2</sup> - Wyle GmbH

<sup>3</sup> - NASA-JSC

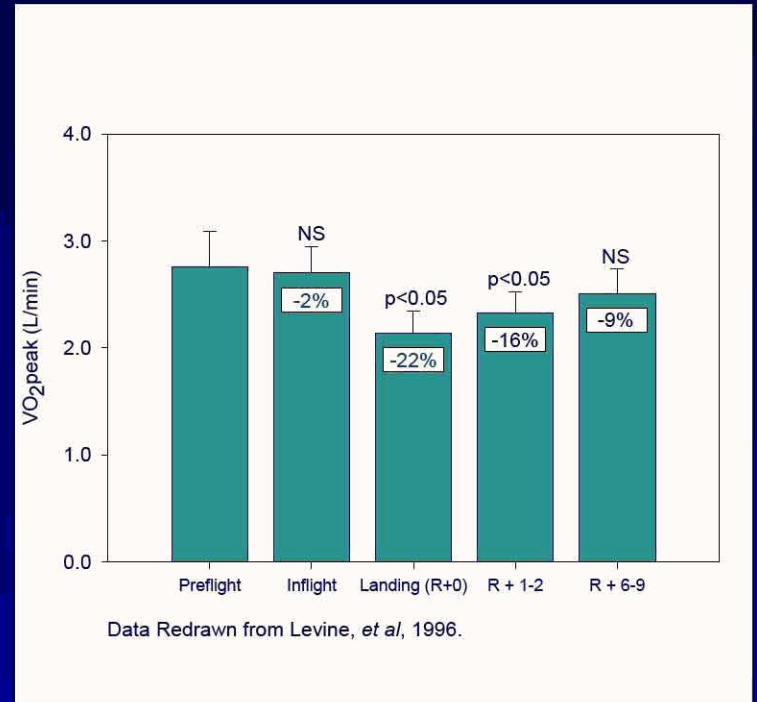
<sup>4</sup> - Lockheed Martin

# Why Preserve Aerobic Capacity?



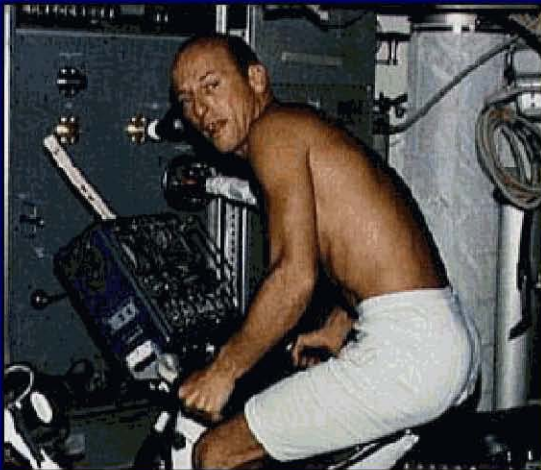
- Maintains the ability to perform endurance activities (e.g. EVA)
- Decrease in rehabilitation time
- Important contributor toward performance of egress following space flight

# Introduction



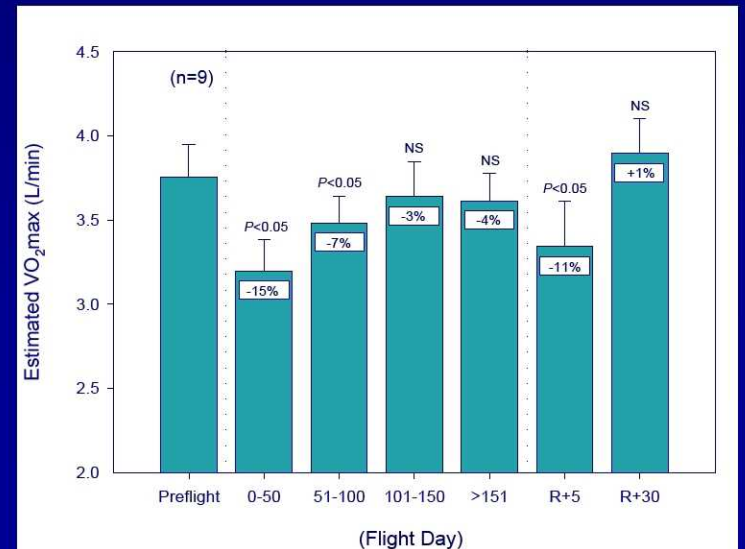
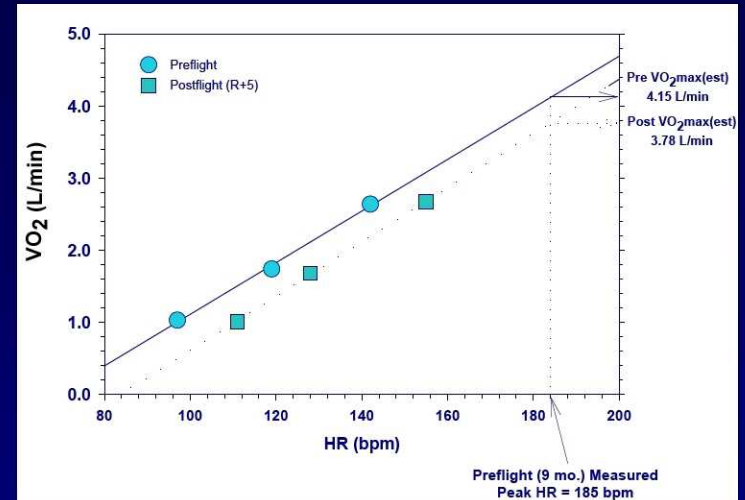
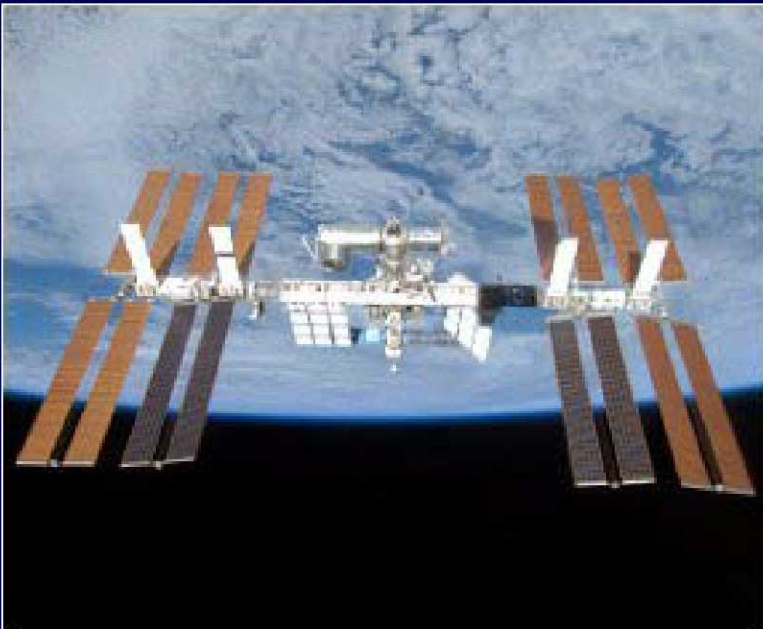
- **Max. HR unchanged**
- **Max. cardiac output (thus max. stroke volume) reduced in proportion to VO<sub>2</sub>peak decline following flight.**
- **Likely d/t reduced plasma volume and reduced venous return.**

# Introduction (Continued)



- Skylab (n=6) - duration 28-84 days
- Submaximal elevated exercise heart rates (HR), decreased exercise cardiac output and stroke volume after flight (R+0 to R+2)
- No substantial change in HR response during flight.
- $\text{VO}_2$  peak measurements attempted during flight. Some crewmembers showed no change, others a decline (Sawin, et al, 1975)
- Recovery time ranged from 10-31 days following flight (Michel, et al, 1977)

# Introduction (Continued)

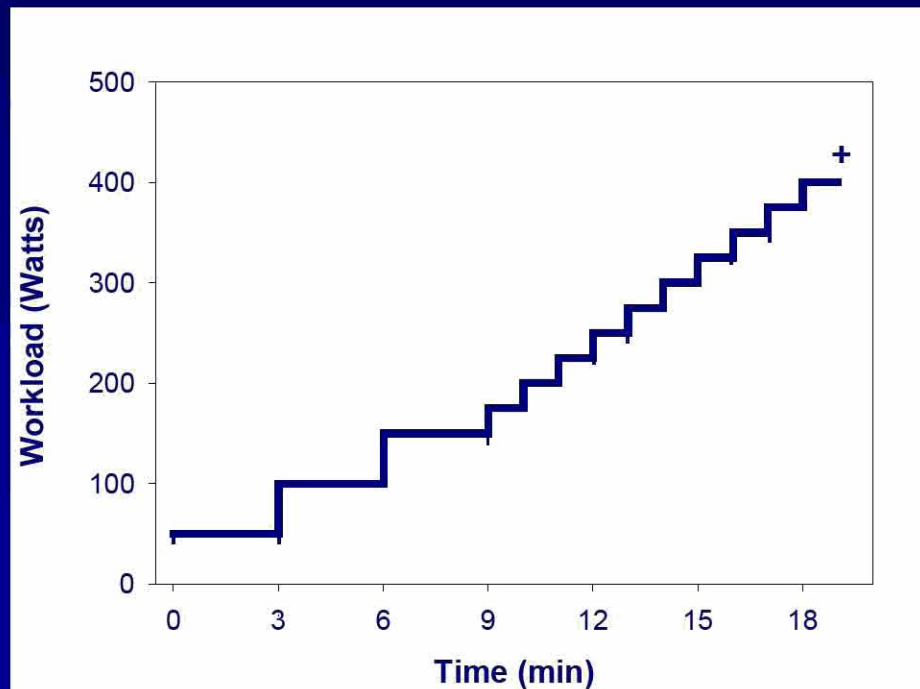


# Purposes

- **To directly measure maximal oxygen uptake during and following long duration missions**
- **To assess the validity of the current methods of estimating aerobic capacity change during and following ISS missions**

# Methods

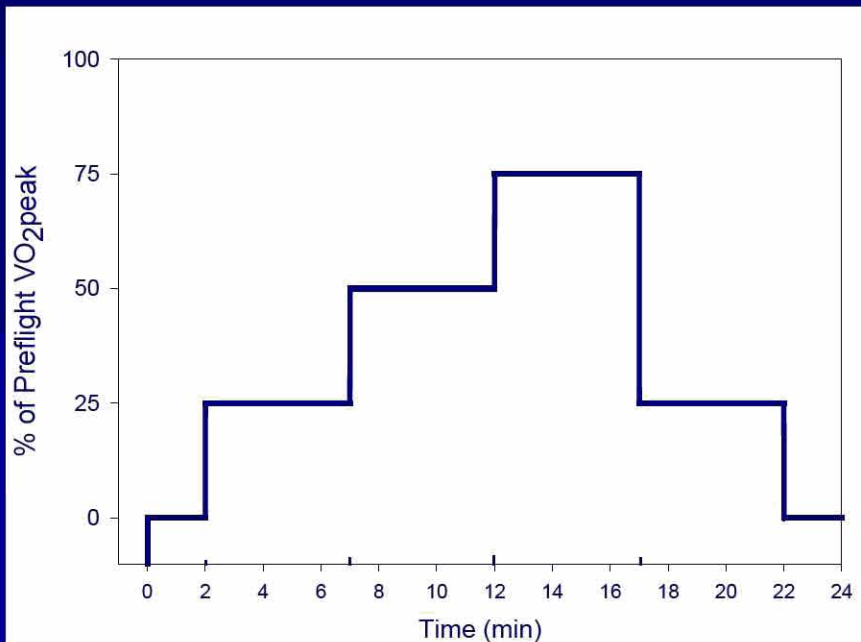
- **Subjects** - astronauts assigned to ISS Expeditions of > 90 days
- **Initial cycle exercise testing** is performed ~ 9 months prior to flight, establishes work rates used for the remainder of experiment
- **Testing** is to “symptom-limited maximum”



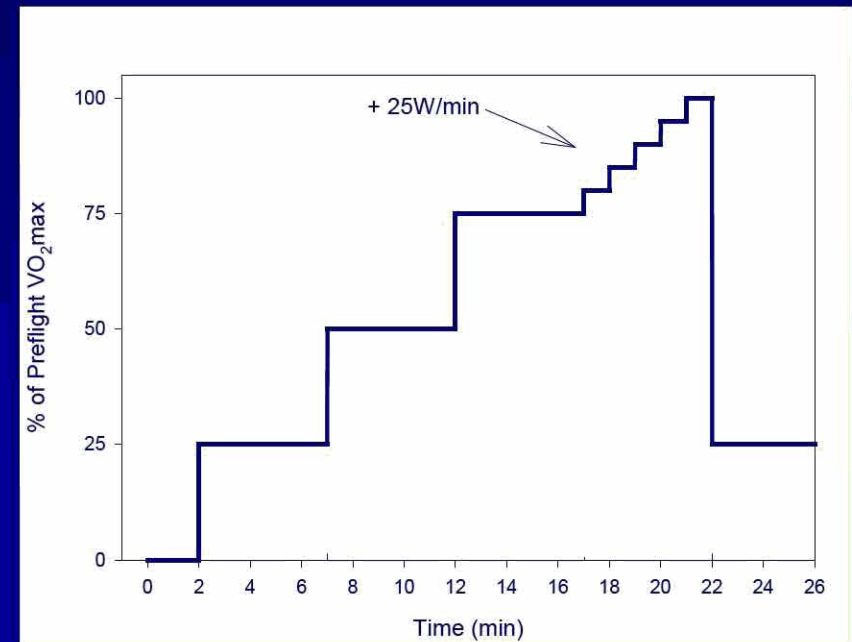
**L-270 Peak Cycle Test**

# Methods (Continued)

- Experiment protocol exercise tests are performed on L-60, L-30, FD15, every 30 FDs thereafter, and on R+1, R+10 and R+30.
- First three stages of exercise are similar to “Periodic Fitness Evaluation” test – a submaximal test used routinely for ISS crews, test continues to maximum.



**Periodic Fitness Evaluation (PFE)**



**VO<sub>2</sub>max Study Experimental Protocol**

# Methods (Continued)

- Measures obtained during testing include:
  - Metabolic gas analysis ( $\text{VO}_2$ , etc.)
  - Heart rate (ECG)
  - Cycle work rate
  - Cardiac output (Rebreathing technique - Freon-22/ $\text{SF}_6$ )
    - ✓ Rest and during last min. of each 5 min stage.
- Device used - the ISS Portable Pulmonary Function System (PPFS)



# Subject Performing Experiment on ISS



# Subject Performing Experiment on ISS

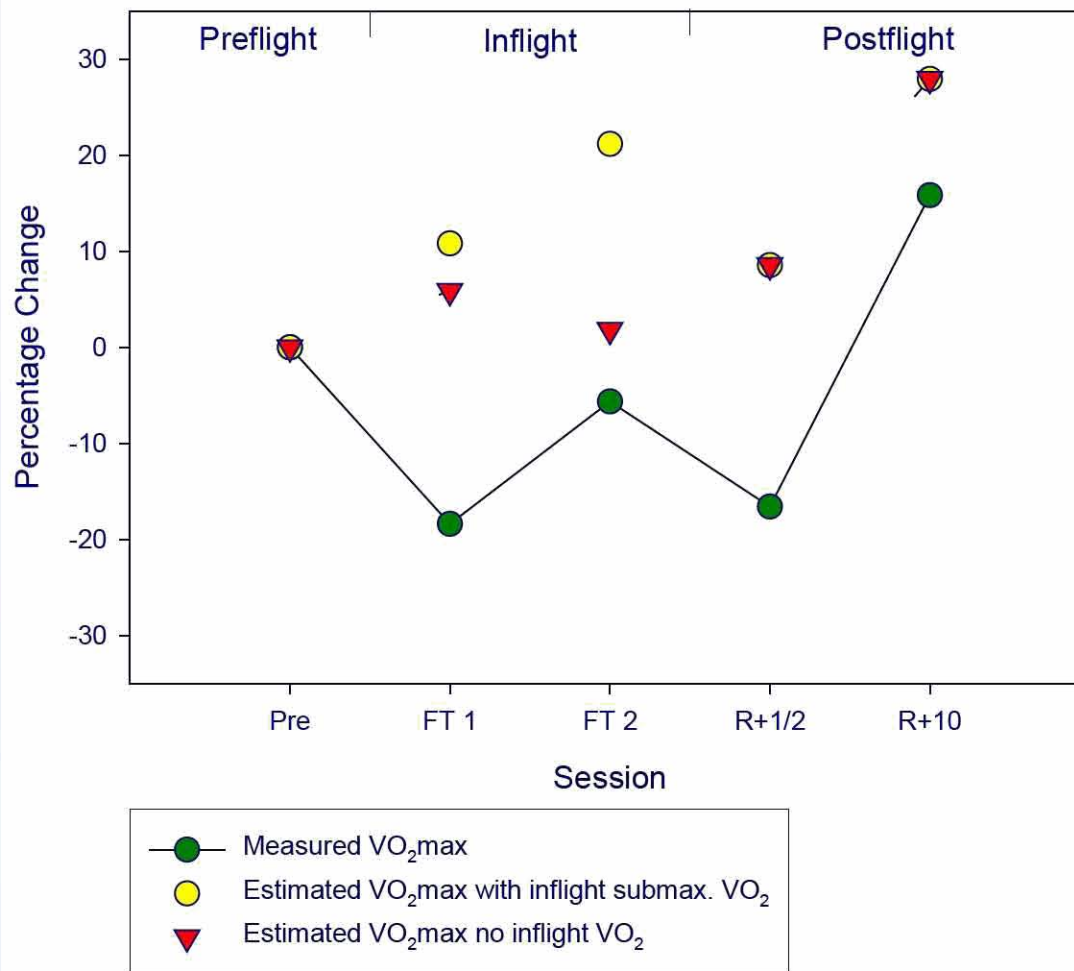


# Results Overview/Limitations

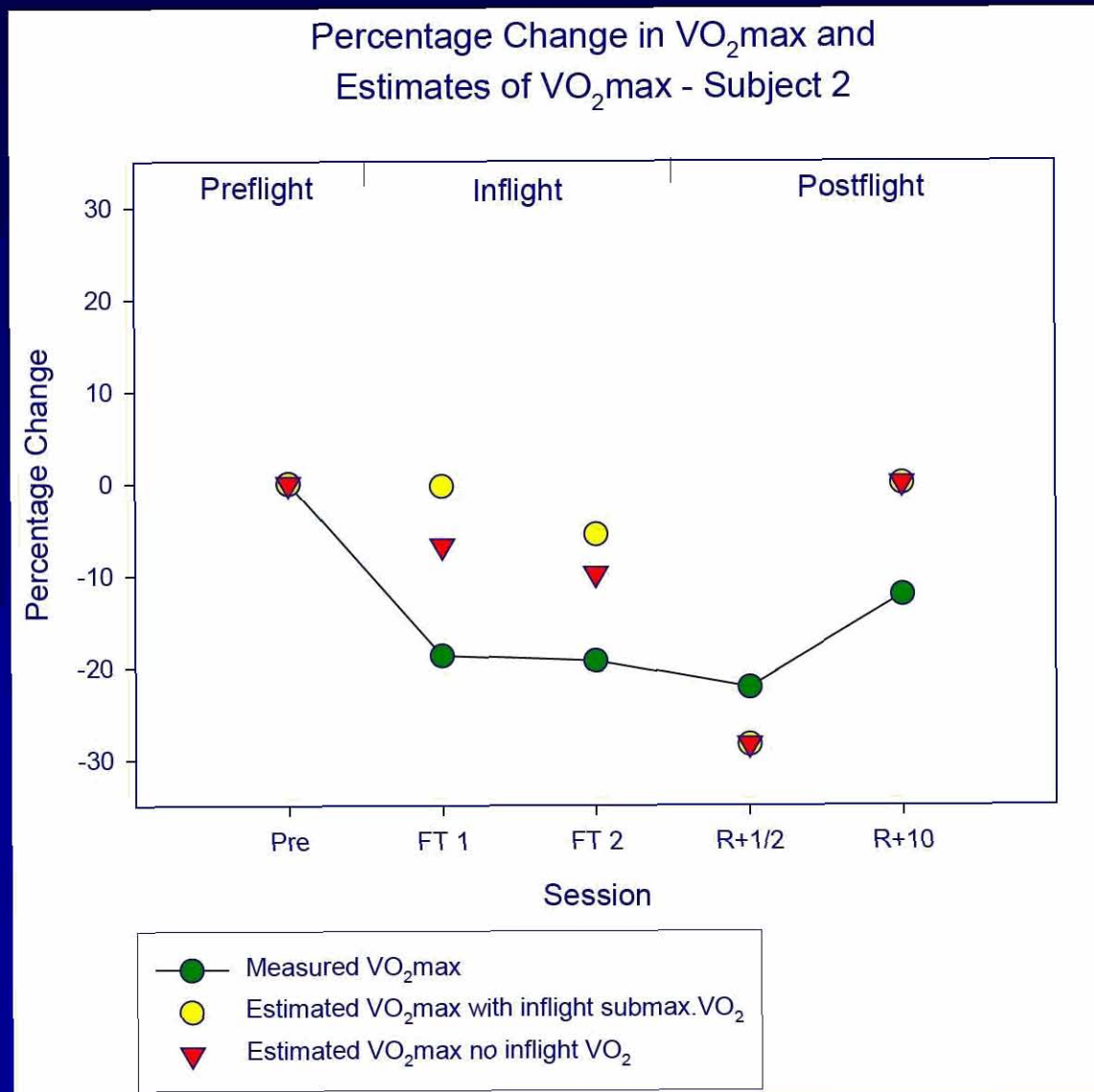
- **N=3, data presented in “case study fashion”**
- **To preserve subject anonymity data is presented as % changes from preflight.**
- **PPFS original delivery to ISS was pushed back d/t launch stowage constraints – delivered to ISS mid – Expedition, thus early inflight measurements not performed.**
  - **Range: Flight days 61 to 167**
  - **Tests within a subject were separated by ~30 days**
  - **Two tests per subject**
- **R+30 data not presented**
- **Cardiac output data has been collected and is in the process of being analyzed, but is not presented today.**

# Results

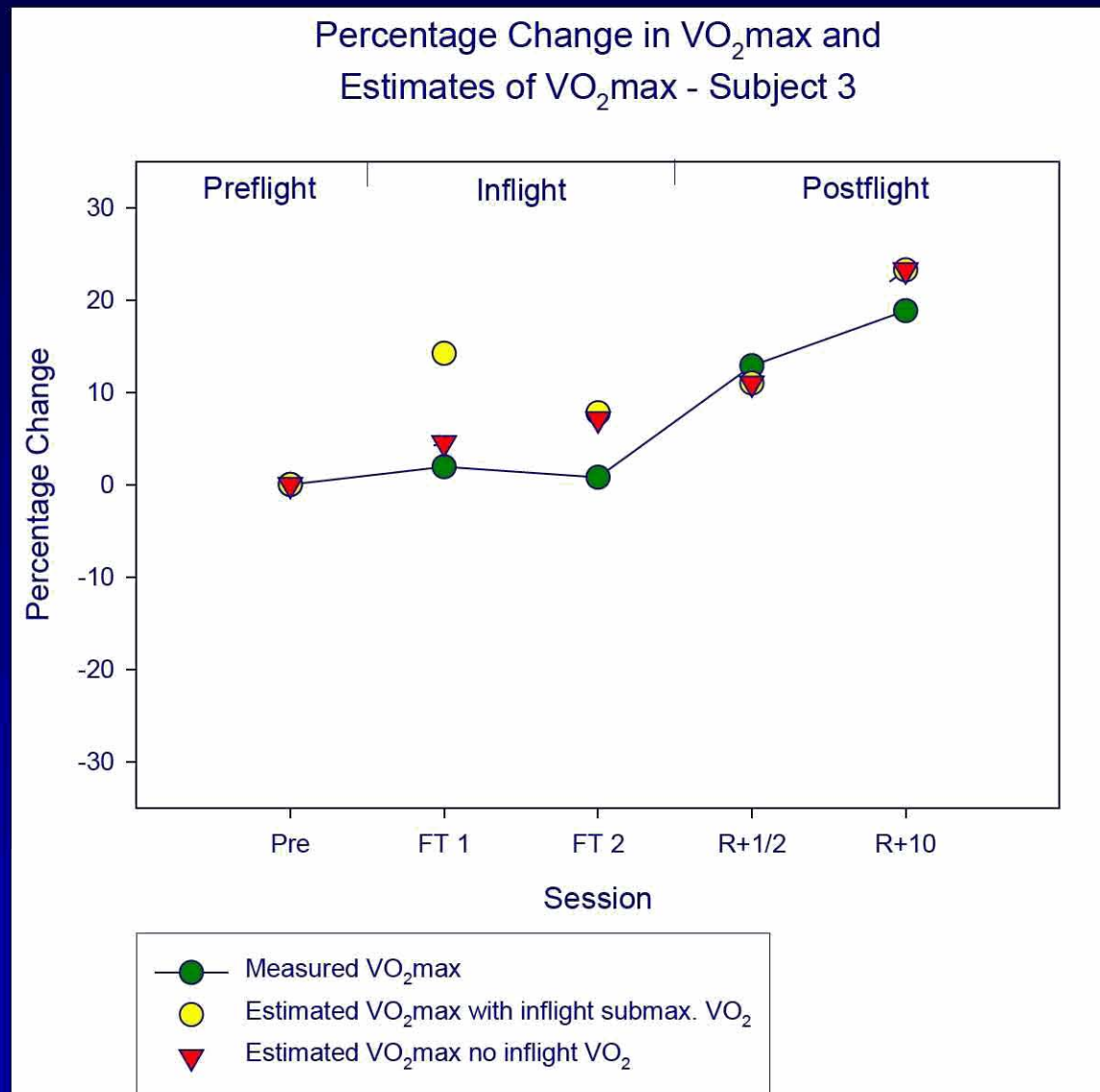
Percentage Change in  $\text{VO}_2\text{max}$  and  
Estimates of  $\text{VO}_2\text{max}$  - Subject 1



# Results (Continued)



# Results (Continued)



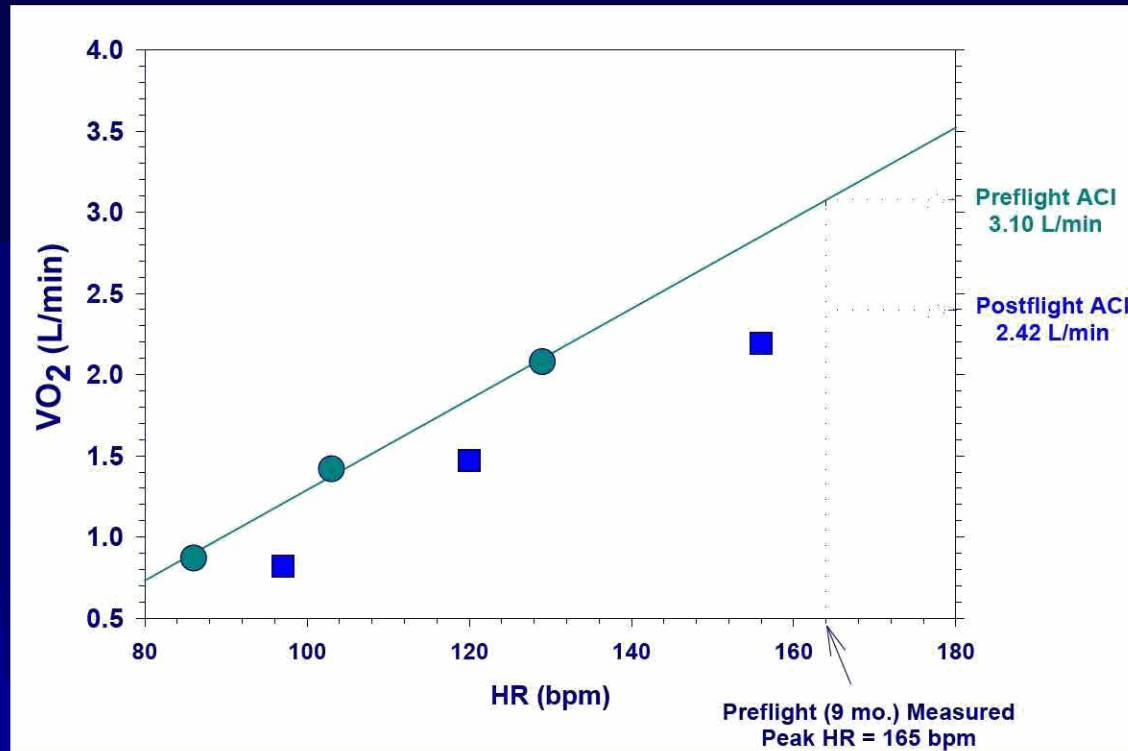
# Discussion/Preliminary Conclusions

- This is very early data – too early to draw firm inferences
- The crewmember with the highest  $\text{VO}_2\text{max}$  preflight experienced the largest decrease in  $\text{VO}_2\text{max}$  inflight and post flight
- The crewmember with the lowest  $\text{VO}_2\text{max}$  preflight experienced the smallest change in  $\text{VO}_2\text{max}$  inflight and post flight
- The submaximal techniques of  $\text{VO}_2\text{max}$  prediction do not seem to track measured  $\text{VO}_2\text{max}$  well
- The effect of preflight exercise/inflight exercise volume on  $\text{VO}_2\text{max}$  change has not been assessed (although the data is being collected).

# Study Plans

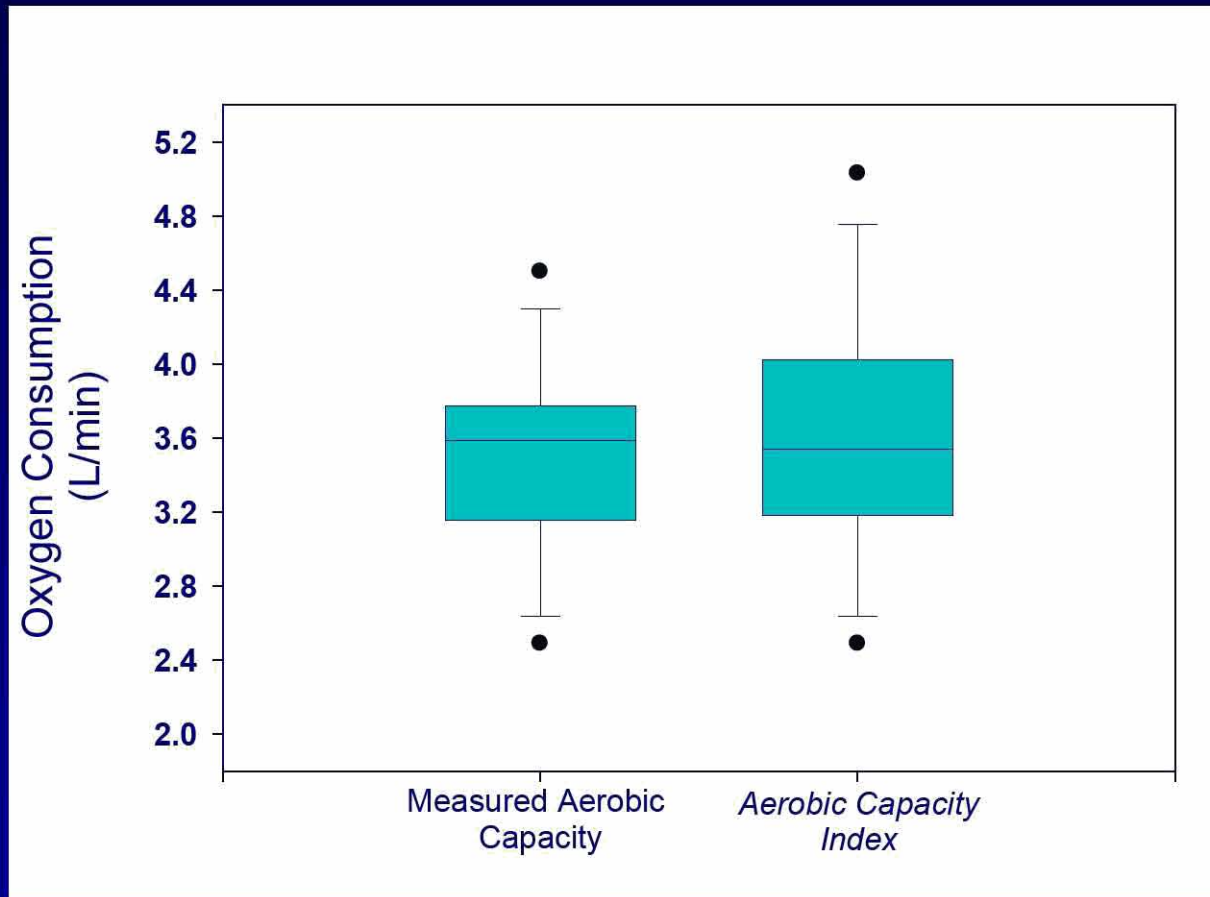
- **Subject currently on-board ISS.**
  - **Preflight, 4 inflight measurements thus far.**
  - **2 additional inflight and post flight measurements planned.**
- **Future Manifest:**
  - **1 subject ISS Exp. 23/24 (22S – March 2010)**
  - **2 subjects ISS Exp. 24/25 (23S – June 2010)**
  - **2 subjects ISS Exp. 26/27 (25S – November 2010)**
  - **1 subject ISS Exp. 27/28 (26S – March 2011)**
  - **1 subject ISS Exp. 28/29 (27S – June 2011)**
  - **1 subject ISS Exp. 29/30 (28S – October 2011)**
- **“Midterm Evaluation” will occur after Exp. 24/25.**

# The $\text{VO}_2$ calculated to occur at peak HR is used as an Aerobic Capacity Index (ACI)



- Linear relationship between HR and  $\text{VO}_2$  for *each test session* is quantified, that is:  $\text{VO}_2 = \text{slope}(\text{HR}) + \text{intercept}$
- This equation is then solved using the crewmember's peak HR (measured 9 mo. preflight)

# How Accurate is the Aerobic Capacity Index?



**Median, Range, 10<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles of aerobic capacity and aerobic capacity index.**